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# Evaluation and analysis of structures with porch system in lightweight concrete by thermally expanded clay from San José de Cúcuta metropolitan area, Colombia

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**Abstract.** The increase in the world population has caused cities to grow vertically, increasing the amount of high-rise buildings, which is why there is a need to develop building materials with greater efficiency, that is, resistant and with less density to the conventional. The objective is to analyze the mechanical behavior of buildings with portico system when being designed with lightweight concrete mixtures made with thermally expanded clay from materials in the San José de Cúcuta metropolitan area, Colombia. Eight structural models were made using the finite element method with the Etabs® software, varying the building height and the concrete type that was used, in order to compare the properties and lightweight concrete characteristics contrasted with the conventional concrete. The modeled buildings were located on land with a capacity of 200 KPa and residential use. The San José de Cúcuta city is located on an area of high seismic threat according to the Colombian construction of resistant earthquake. It was determined that lightweight concrete manufactured with materials from the San José de Cúcuta metropolitan area, Colombia, is structural since it has a compressive strength at 28 days of 26 MPa on average and equilibrium density of 1646.16 Kg/m<sup>3</sup> complying with the requirements minimums required by the Colombian regulation of resistant earthquake construction for a concrete to be considered light and structural. It was found that when using lightweight structural concrete in the design of joists and slabs, there is a 10% decrease in dead loads that reach the foundations of the structure, which implies a reduction in the dimensions of the foundations.

## 1. Introduction

The growth of the world population has meant that cities have a vertical growth, that is, the number of high-rise buildings has increased over the years [1], which is why the study of materials of greater efficiency, which has led to the investigation of structural lightweight concrete produced with thermally expanded clay. Lightweight structural concrete is a material that has been used for more than 100 years in the construction of buildings [2,3], the density of structural lightweight concrete typically varies between 1120 kg/m<sup>3</sup> and 2000 kg/m<sup>3</sup> [4,5], and it is produced with lightweight natural aggregates such as pumice, diatomite and slag, or with lightweight artificial calcination clay aggregates [4-9].

It's known that lightweight concrete produced with thermally expanded clay, tend to have lower compressive strengths than conventional concrete and also have lower modulus of elasticity, in other words, lightweight concrete is up to 40% more elastic than conventional concretes [10-12].

Several authors have studied the structural behavior of lightweight concrete, including it in structural models as the main construction material, as well as: Bueno Quintero D [13], who determined that in buildings of 15 stories high there are savings of up to 15% in concrete and 22% in steel; Correa



Chaparro J and Ratti Guzmán G [11], determined that there is a decrease between 5 and 10% of the total weight of the structure when using lightweight concrete.

According to the authors studied [11-13], it's necessary to investigate the lightweight concretes when using them in structures with gantry systems in the secondary elements, that is, to make use of this concrete for the design of floor slabs and roof (tiles and joists), because these elements aren't designed to resist seismic energy, since the structural elements that dissipate the energy produced by the seismic effect are the columns and beams [14], so these elements would be designed with conventional concrete that is more rigid.

In this article, eight buildings are modeled: four with conventional concrete in all structural elements; and four using lightweight concrete in joists and slabs, and conventional concrete in beams and columns. It is expected that with the results, materials with greater efficiency in construction can be developed, that is, that they have a greater compressive strength and a lower density than conventional materials.

## 2. Methodology

Eight structural models were made: four structures designed in its entirety by conventional concrete varying the amount of floors (3, 4, 5 and 6 floors); four structures designed with columns and beams in conventional concrete and joists and slabs with lightweight concrete, varying the height of the building (3, 4, 5 and 6 floors). The proposed structural models will be tested in the same conditions in order to compare the results obtained.

The structures were modelled with the help of the Etabs® software, which is a program of the company Computer and Structures Inc., Spain. The colombian earthquake-resistant construction regulation NSR-10 [14] was used as normative for the design of structural models. The buildings were defined as residential with type I use group, they were located in the San José de Cúcuta city, Colombia, which is located on the high seismic hazard zone, according to the NSR-10 [14], as well as being appreciated in Figure 1. The type of soil was determined as classification C with an allowable capacity of 200 KPa.

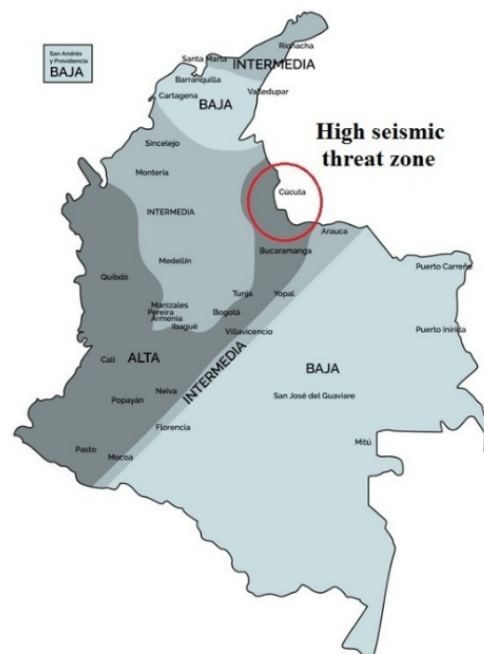


Figure 1. High seismic threat zone [14].

A spectral dynamic analysis was carried out to determine the seismic forces per floor, assuming a rigid diaphragm at the level of each mezzanine and roof. Figure 2 shows the elastic spectrum of design accelerations given for the seismic hazard zone in the type of soil mentioned above.

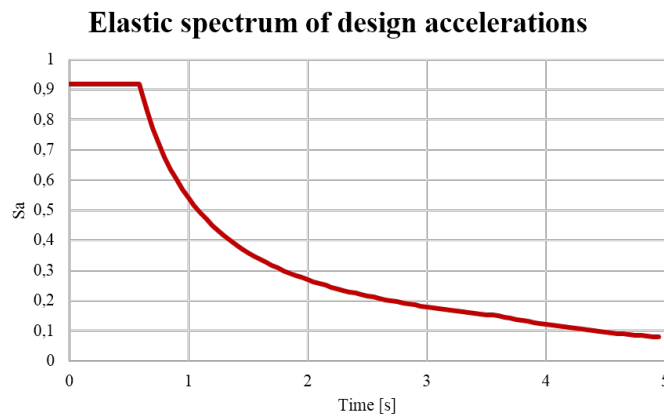


Figure 2. Elastic spectrum of design accelerations [14].

Figure 3(a) shows the typical mezzanine architectural floor with which the structural models were made, and Figure 3(b) shows the typical structural floor plan with the beams and joists located and dimensioned (beams 30 cm wide by 40 cm high, and joists 15 cm wide by 35 cm high), the columns have only been located because the dimension of these varies depending on the need that is required to comply with the parameters exposed by NSR-10 [14]. The structural plants shown in Figure 3(a) and Figure 3(b), are typical for structural models of conventional concrete and lightweight concrete, this is done in order to make comparisons between the results obtained, the height of the pee, measured between the axis of the slabs, was considered as 3 m.

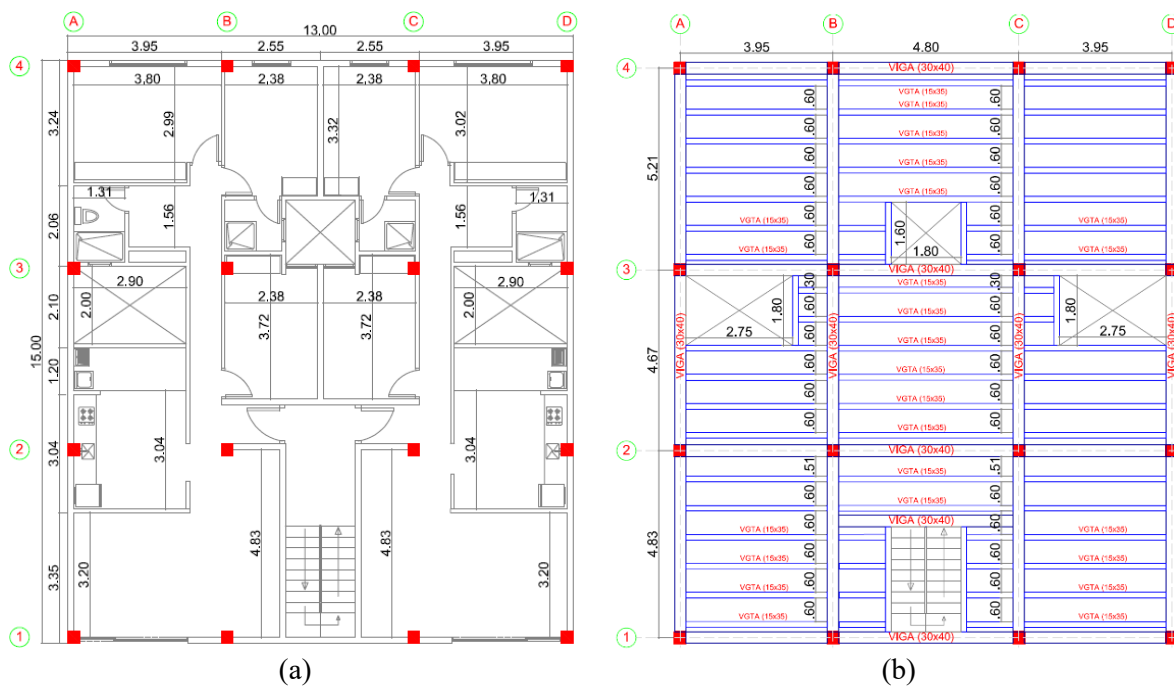


Figure 3. Elastic spectrum of design accelerations.

### 3. Results

With the dimensioned structural plant, an analysis of live load and dead load was made, considering the weight of the non-structural dividing walls, the floors and finishes, the ceiling, the weight of the slabs and the lightening used. Table 1 shows the weight of each of the components described above, together with the analysis of dead load and live load performed for models with conventional concrete and lightweight concrete.

**Table 1.** Load analysis in the mezzanine slab.

Element	Lightweight concrete (kN/m <sup>2</sup> )	Conventional concrete (kN/m <sup>2</sup> )
Tile	0.90	1.20
Twist	1.08	1.44
Relief	0.30	0.30
Dividing walls	3.00	3.00
Ceiling	0.50	0.50
Floor finishes	1.10	1.10
Total, dead load (D)	6.88	7.54
Total, live load (L)	1.80	1.80

The mechanical properties of the concretes used for the modelling of the structures are shown in Table 2, said properties are: equilibrium density, resistance to compression at 28 days, and the modulus of elasticity according to the Colombian regulation of construction earthquake resistant.

**Table 2.** Mechanical properties of lightweight and conventional concrete mixtures.

Type of mixture	Equilibrium density (kg/m <sup>3</sup> )	Compressive strength (MPa)	Modulus of elasticity (MPa)
Lightweight	1646.16	26.33	14736.76
Conventional concrete	2239.06	26.51	23456.97

The colombian regulation of earthquake resistant construction [14], presents that the structure in zones of high seismic hazard, must have a design with dissipation of special energy, in which it shows that the dimension of the columns can't be less than 30 cm in systems of frames, and in addition, the drift can't exceed 1% of the height of the floor, which in this case can't be more than 3 cm. Table 3 shows the dimension of the column, the drift in percentage, for each one of the models made (structure all in conventional concrete and structure with lightweight concrete in slabs and conventional concrete in columns and beams).

**Table 3.** Column dimension and maximum drift for the models made.

Number of floors	Model with conventional concrete		Model with lightweight concrete and conventional concrete	
	Dimension of columns (cm)	Maximum drift in percentage (%)	Dimension of columns (cm)	Maximum drift in percentage (%)
3	35 x 35	0.968	33 x 33	0.992
4	46 x 46	0.999	44 x 44	0.987
5	60 x 60	0.992	55 x 55	0.992
6	70 x 70	0.995	66 x 66	0.995

In Table, 3 it's shown how the dimension of the columns in the models that the lightweight concrete is implemented is smaller than the dimension of the columns of the models with conventional concrete, the decrease of the size of the columns was determined of approximately 5%, which implies a smaller amount of concrete for the construction of the building and therefore a smaller amount of construction materials.

In addition, Table 3 shows that the increase in the section of the columns is not constant as the building becomes higher. To comply with the maximum drift in the 4-story building, the increase in the size of the column was between 30% and 35% with respect to the 3-story building, in the 5-story building the increase in the column was between 25 and 30% with respect to that of 4 floors, and in the 6 floors an increase between 15% and 20% was determined with respect to the 5 floors.

The reduction of the weight of the slabs of mezzanine and roof, and the decrease in the dimensions of columns to meet the drift of floor, causes the total weight of the structure to decrease, which makes the structural elements of the foundation have a dimension lower to comply with the parameters required by the Colombian earthquake resistant construction regulation NSR-10 [14]. Table 4 shows a comparison between the dead load that reaches the base of the building between the structural models carried out.

**Table 4.** Comparison between the deadweight of lightweight concrete models and conventional concrete models.

Number of floors	Conventional concrete building weight (kN)	Lightweight concrete building weight (kN)
3	4285.11	3919.09
4	6347.88	5837.94
5	8922.94	8070.31
6	11705.44	10698.66

Table 4 shows the difference that was determined in the dead loads that reach the foundation, it is observed that no matter what the height of the building the proportion between the weight is maintained in a similar way, decreasing the total weight of the structure by 10%.

#### 4. Conclusions

It was determined that when using lightweight concrete in secondary elements (tiles and joists), the size of the columns is reduced by 5%, which implies that the amount of conventional concrete is reduced, for the construction of the main structural elements (columns and beams).

The increase in the size of the columns is not constant as the number of floors increases, since it was determined that a structure of 4 floors presents an increase in the section up to 35% with respect to a similar structure of 3 floors, while a 6-story structure presented an increase of approximately 20%, compared to a structure in the same 5-story condition.

A 10% decrease in the dead loads that reach the foundation of the structure was demonstrated when using lightweight concrete in the design of secondary structural elements (tiles and joists), which implies a reduction in the dimensions of the structural elements of the foundation to comply with the design parameters stipulated in the Colombian regulation of earthquake-resistant construction.

It is recommended the study of the mechanical behavior of lightweight concrete in other types of structures, in order to determine in which of them is the greatest engineering benefit in the use of the material.

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